INFILTRATION AND EROSION ANALYSIS OF PHOSPHATE STRIP MINE OVERBURDEN

Christopher M. Knopp
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USDA Forest Service Research Paper INT-246
Intermountain Forest and Range Experiment Station
U.S. Department of Agriculture, Forest Service

COVER PHOTO

A phosphate mine overburden waste dump in southeastern Idaho. Surface wastes have differing hydrologic responses, i.e., different water infiltration and soil erosion rates. Soil color is a useful indicator of the differences. Light yellowish-brown soils, Munsell 10YR 6/4, have the greatest erosion rates, while very dark gray-brown soils, Munsell 10YR 3/2, have the smallest erosion rate. The brown soils, Munsell 10YR 5/3, are intermediate.

The open pit is at the top left.

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May 1980

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THE AUTHORS

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RESEARCH SUMMARY

The objective of this study was to identify separate sedimentary strata on the surface of one phosphate mine overburden dump and to compare those strata in terms of their respective infiltration and erosion characteristics.

Sedimentary strata were initially identified solely by color. This identification was then verified by comparing the following physical characteristics: minerology, bulk density, texture, antecedent moisture, and modulus of rupture.

Three geologic strata on soil types were identified. Of those three, two soils were believed to originate from distinct separate strata of rock, while the third is believed to be a mixture of several strata.

The two elemental soil types exhibited significantly different infiltration constants (f_c) and soil loss quantities as a result of tests run with a drip type infiltrometer. The dark soil type had an average f_c of 1.73 inches/hour (4.39 cm/h) and an average soil loss of 2.1 tons/acre (4.7 MT/ha), while the light soil type had an average f_c of 0.95 inch/hour (2.41 cm/h) and an average soil loss of 23.2 tons per acre (52.0 MT/ha) for the 30-minute infiltrometer test.

Using the soils' physical characteristics, a stepwise multiple linear regression equation was derived in order to permit future identification of desirable soil types.

The implications of this research are that by separating individual geologic strata for use as topsoil, significant improvements in dump stability and erosional losses may be possible.

CONTENTS

INTRODUCTION

The Maybe Canyon phosphate mine is one of six currently active strip mines in southeastern Idaho. Continued operation of this mine will produce 130 acres (52.6 ha) of pit and 200 acres (80.9 ha) of new overburden dumps (U.S. Geological Survey 1977). To limit erosion and promote revegetation, specific dump construction procedures have been recommended. One of the most important involves surfacing the dumps with native topsoil. The surface covering is a critical element because it serves as the foundation for future reclamation and as the source of potential sediments.

Because of the generally shallow soils, the stockpiling of topsoil was not practical in this case. Instead, the Maybe Canyon mine is primarily surfaced with overburden shales and mudstones.

The objective of this study was to analyze the infiltration rates and soil erodibilities of the surface materials on one completed phosphate mine overburden dump. Secondly, we wished to isolate some specific characteristics which could be used to identify those strata exhibiting desirable hydrologic properties.

SITE DESCRIPTION

The Maybe Canyon mine, dump No. 2, is located northeast of Soda Springs, Idaho, (fig. 1). It is approximately 4.9 acres (2.0 ha) in area, has a northeast aspect, and is at about 7,700 feet (2 350 m) elevation. Slopes on the overburden material range from 15 to 34 percent. At the time of this study, the dump was approximately 2 years old, and had only a sparse covering of grass, despite having been machine seeded.

The average annual precipitation is estimated to be 22 inches (56 cm), 54 percent of which occurs as snow, the rest predominantly as summer thundershowers. Temperatures are estimated to range from -42°F to 92°F (-41°C to 33°C). Winds are predominantly from the southwest (Jeppson and others 1974).

The surface of the overburden dump appears to be composed of natural topsoil. It contains little rock since the shales and mudstones used to surface the dumps are soft and subject to rapid decomposition as a result of carbonate leaching. For the sake of brevity, these surface materials will be referred to as "soils", even though they exhibit no noticeable pedogenic features.

METHODOLOGY

Organization

Infiltrometer sampling sites consisted of 12 slope-soil combinations each containing one of four slope categories (15-19 percent, 20-24 percent, 25-29 percent, and 30-34 percent) and one of three soils which were initially identified only by the Munsell soil color. The dark soil is a Munsell 10YR3/2 (very dark gray brown); the medium soil is 10YR5/3 (brown); and the light soil is 10YR6/4 (light yellowish brown). For ease of discussion, the dark, medium, and light soil type labels have been retained throughout this paper. Four infiltration runs were made on each slope-soil combination. One slope-soil combination was not present over a large enough area for four sampling runs; so the total number of sampling plots was 45 instead of the planned 48.

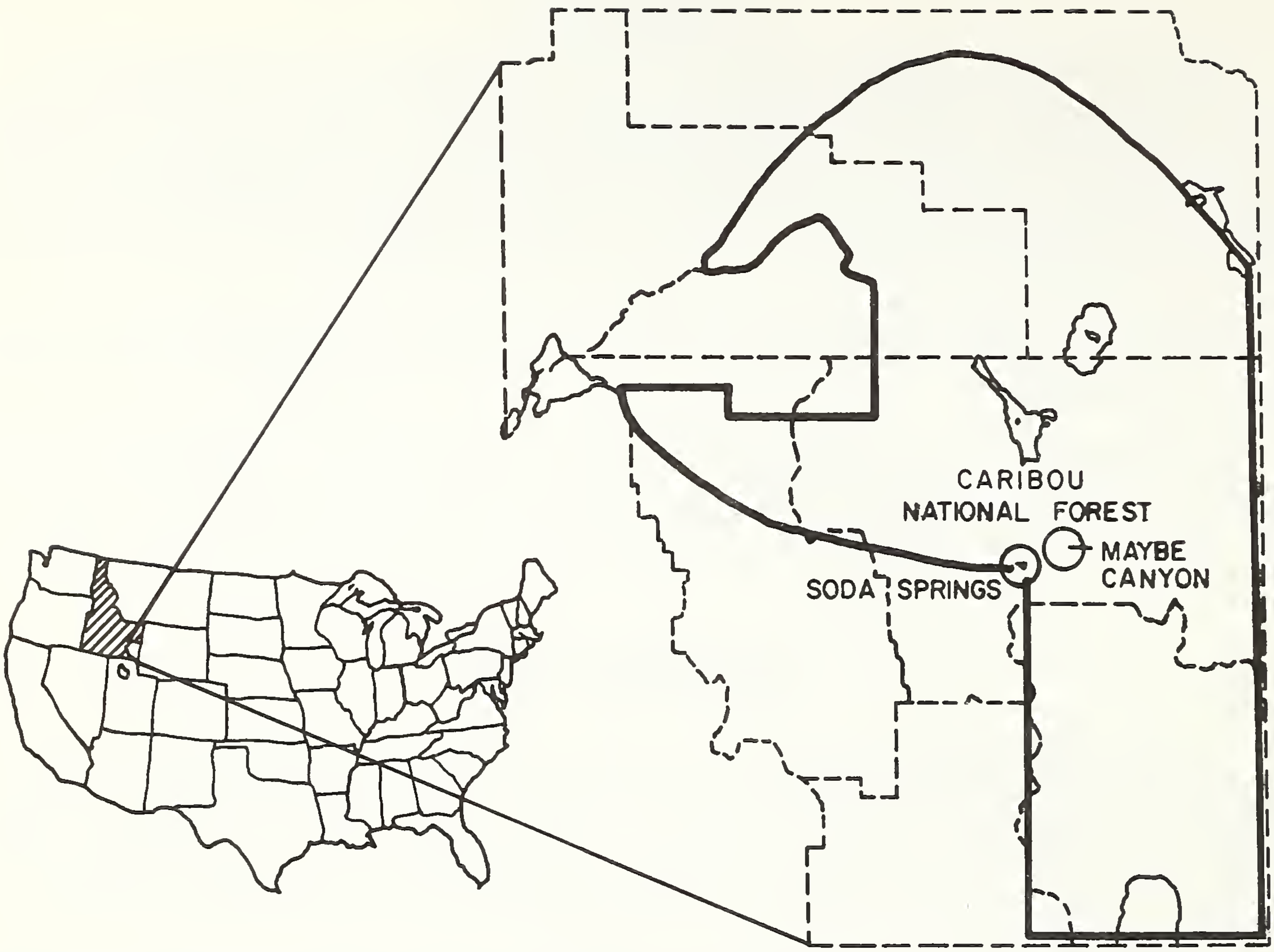

Figure 1.--Map of southeastern Idaho. Heavy lines enclose general phosphate mining areas (U.S. Geological Survey 1977).

Field Procedure

Infiltration rates were determined using a Nevada type drip infiltrometer, designed by Meeuwig (1970). All infiltrometer runs were of 30-minute duration, with runoff samples being collected every 5 minutes. Application intensity was 3.0 inches per hour (7.6 cm per hour). This intensity was required in order to define an infiltration curve on the dry soils.[1] Instrument height was 4.0 feet (1.22 m) on the downslope side with the infiltrometer level.

From each infiltrometer run, six infiltration rates were obtained corresponding to the 0.042, 0.125, 0.208, 0.292, 0.375, and 0.458 hour times.

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[1]Under natural conditions, overland flow will only occur when the soil surface layers are saturated. This condition occurs regularly during the spring snowmelt period or during a rare high-intensity rainstorm.

The weight of soil washed from each plot by raindrop splash and overland flow during the 30-minute run is considered an index of soil erodibility (Meeuwig 1970). Runoff water was collected for each plot. A quart sample of thoroughly mixed water was ovendried and weighed to determine sediment yield. The sediment samples were then used as a comparative measure of erosivity.

Concurrent with the infiltrometer runs, soil samples of the surface 4 inches (10.2 cm) were taken to determine bulk density, soil texture (coarse, sand, silt, and clay percents), antecedent soil moisture, mineral constituents, and modulus of rupture. Mudulus of rupture (MOR) is primarily a measure of the crusting potential of a soil (a high MOR value indicates strong crusting potential) (Richards 1953).

RESULTS

An X-ray diffraction analysis of the three soils showed no significant differences among the three soils for the minerals tested. A one-way analysis of variance (AOV) of the bulk density, antecedent moisture, percent sand, silt, clay, coarse fraction, and modulus of rupture indicated that some significant differences did exist among the three soils. Bulk density and percent sand were very similar for the three soils and showed no significant differences. Antecedent moisture, coarse fraction, silt and clay textural fraction, and modulus of rupture, however, all showed significant differences among the three soil groups at the 0.05 level (figs. 2-5). The dark soil exhibited the highest average antecedent moisture content (5 percent), while the light soil had the lowest (2 percent). The medium soil's antecedent moisture content was similar to the light soil's (2.5 percent), but slightly higher.

The textural differences were generally small. The light colored soil appears to have approximately 15 percent less coarse material (greater than 2 mm in diameter), shows a corresponding increase in its silt fraction, and a slight increase in its clay content. Other textural categories among the three soils displayed no statistically significant differences.

Modulus of rupture values displayed clear differences among the three soil types. The dark soil group exhibited the lowest modulus of rupture, indicating low structural strength in its surface crusts, while the light soil group had the highest average MOR values. The light soil's MOR values were approximately eight times the dark soil's MOR values. Modulus of rupture figures for the medium soil type fell midway between the values of the light and dark soil types.

Infiltration

Horton's (1940) infiltration equation was used to describe the three soils' infiltration characteristics because of its accuracy and simplicity of application.

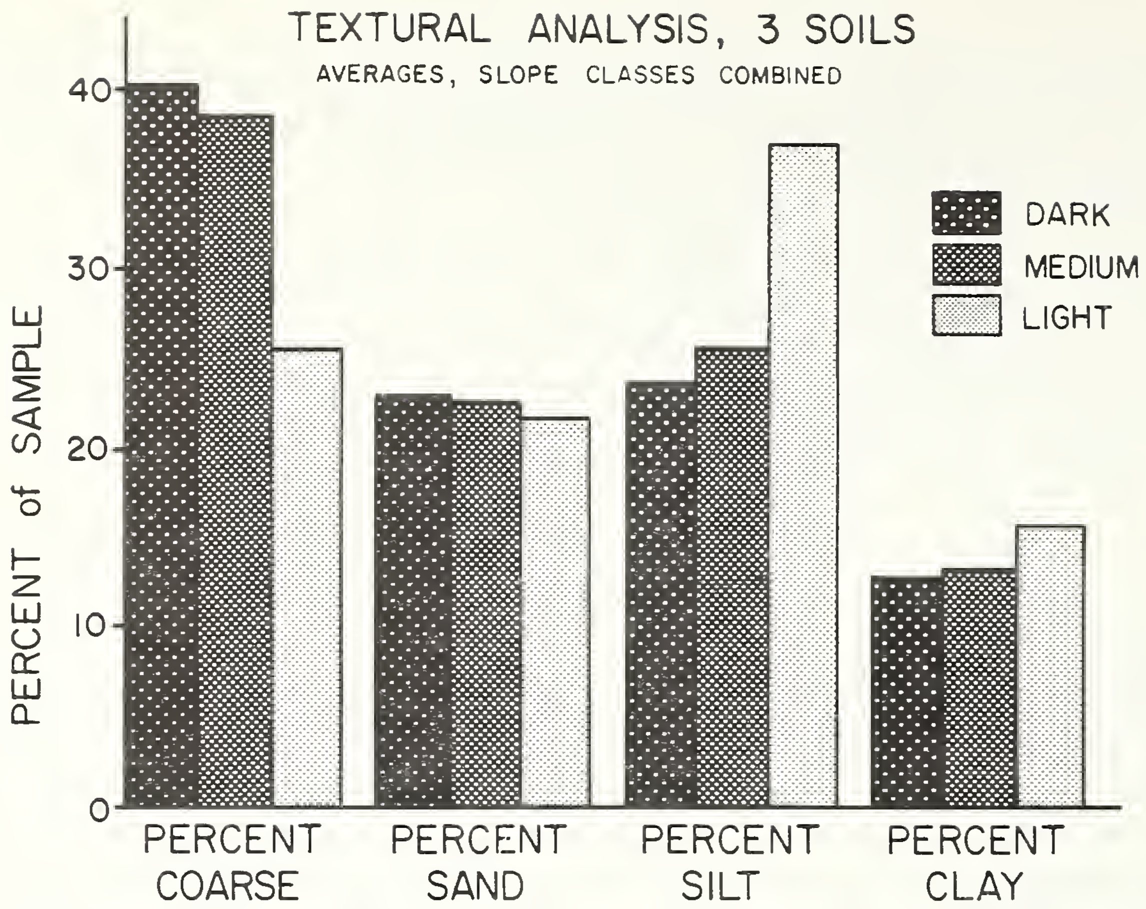
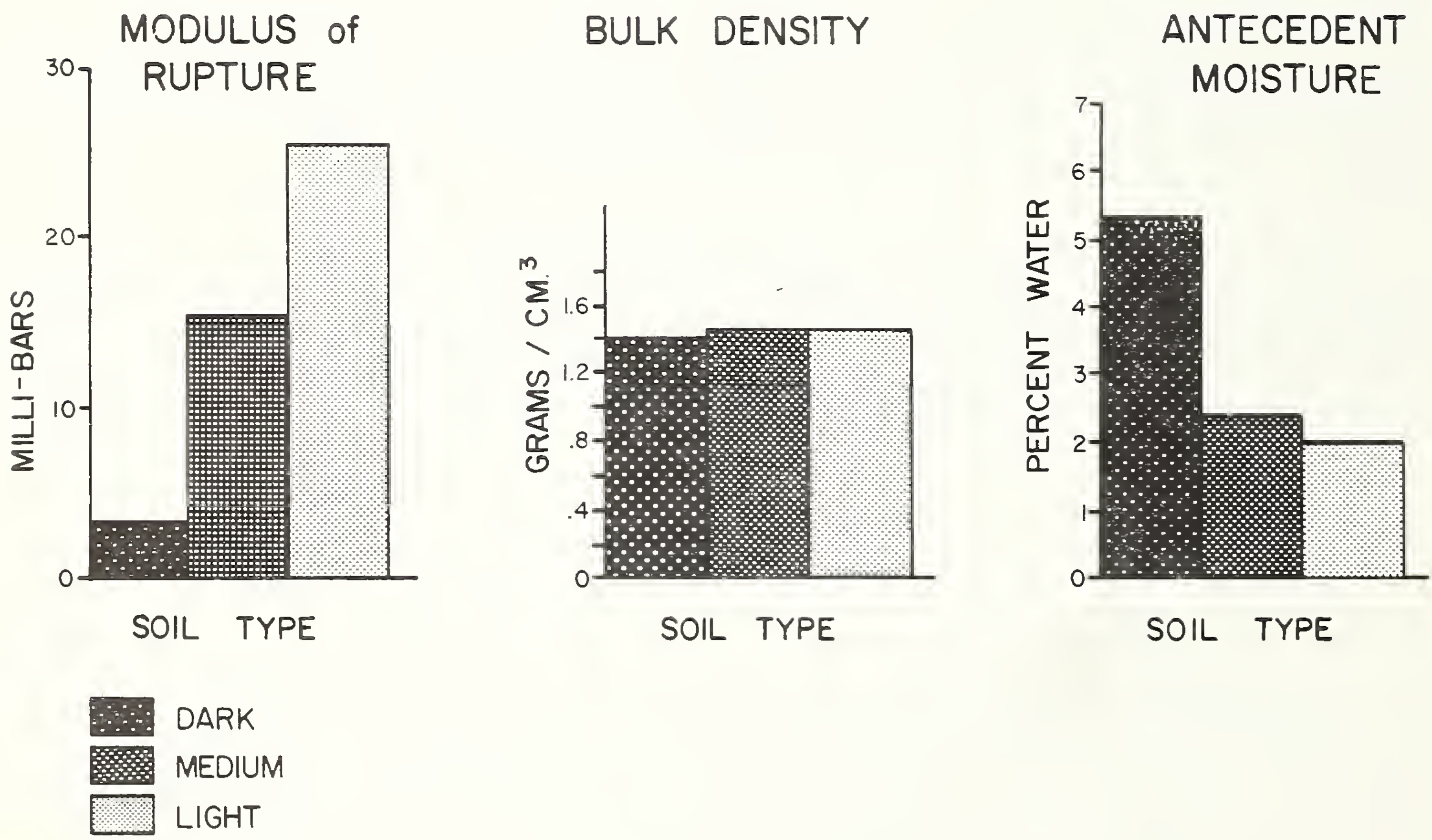


Figure 2.--Textural analysis of the three soils used to surface the Maybe Canyon mine, dump No. 2.



Figures 3 to 5.--Physical characteristics of the three soils present on the surface of the Maybe Canyon mine, dump No. 2.

Horton's equation is:

$$f_t = f_c + (f_o - f_c)\, e^{-kt}$$

where

f_t is the infiltration rate at time t (inches/hour)

f_o is the initial infiltration rate (inches/hour)

f_c is the infiltration constant (inches/hour)

k is the infiltration curve decay factor

t is the time in hours.

The procedure to fit generalized infiltration equations for each slope category and each soil type was to average the six corresponding infiltration rates produced by the infiltrometer runs within each group (the six rates corresponded to the 0.042, 0.125, 0.208, 0.292, 0.375, and 0.458 hour times).

This resulted in a set of six average infiltration rates. These averaged rates were then utilized in a computer solution of Horton's infiltration equation. This was done for all three soil types and for the four slope classes within each soil type (the light soil type only ranged over three slope classes).

The dark soil exhibited the highest calculated infiltration constant, with an f_c of 1.73 inches per hour (4.39 cm/h), the medium soil group had an average f_c of 1.08 inches per hour (2.74 cm/h), and the light soil reflected the lowest average infiltration constant of 0.95 inch per hour (2.41 cm/h) (fig. 6).

The fit of the generalized infiltration equations for the three soils was dependent upon the degree of variability in infiltration rates that particular soil exhibited with respect to different slopes. All of the soils exhibited trends of decreasing infiltration constants with increasing slopes (figs. 7, 8, 9). The dark soil group displayed the greatest variability of infiltration constants among slope classes and so its generalized infiltration equation had the poorest fit.

The medium soils had a much reduced response, while the light soil type showed no statistically significant differences of infiltration constants between slope classes. Because of this slope-induced variation, the r-square values for the three soil types average infiltration equations were: dark soil, r^2=0.27, medium soil, r^2= 0.84, and light soil, r^2 = 0.98.

An analysis of variance (AOV) indicated that significant differences did exist among the three soils f_c's at $\sigma = 0.05$. A Duncan's multiple range test did not show significant differences among any of the three soils f_c values at 0.05; however, the dark and light soils f_c's were extremely close to being significantly different. The failure of the multiple range test to reveal significant differences is probably the result of the less conservative nature of analysis of variance and at least partially because of the fairly high slope-induced variability of the infiltration rates.

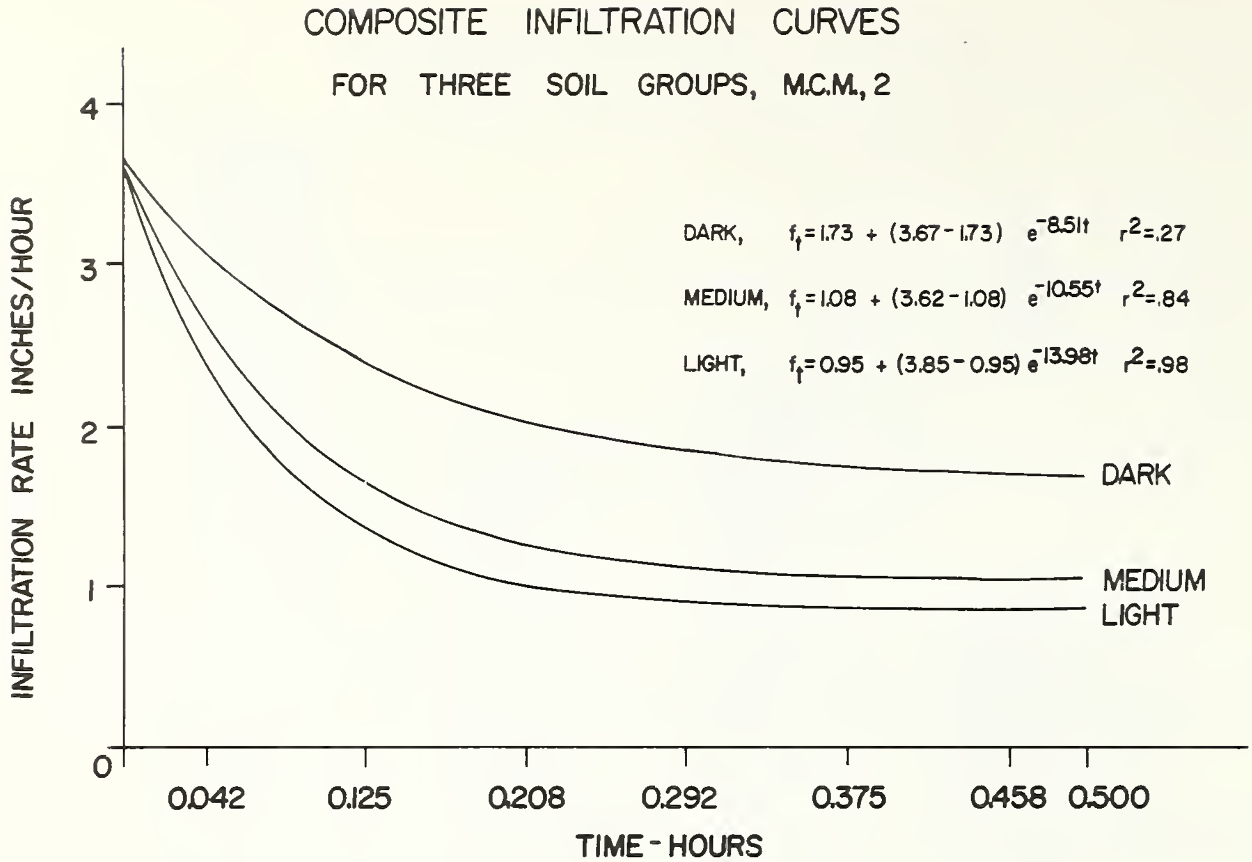


Figure 6.--Horton's average infiltration equation for three surface soils at the Maybe Canyon mine, dump No. 2. The dark and medium curves represent 16 infiltrometer runs of 6 observations each. The light curve represents 13 runs of 6 observations.

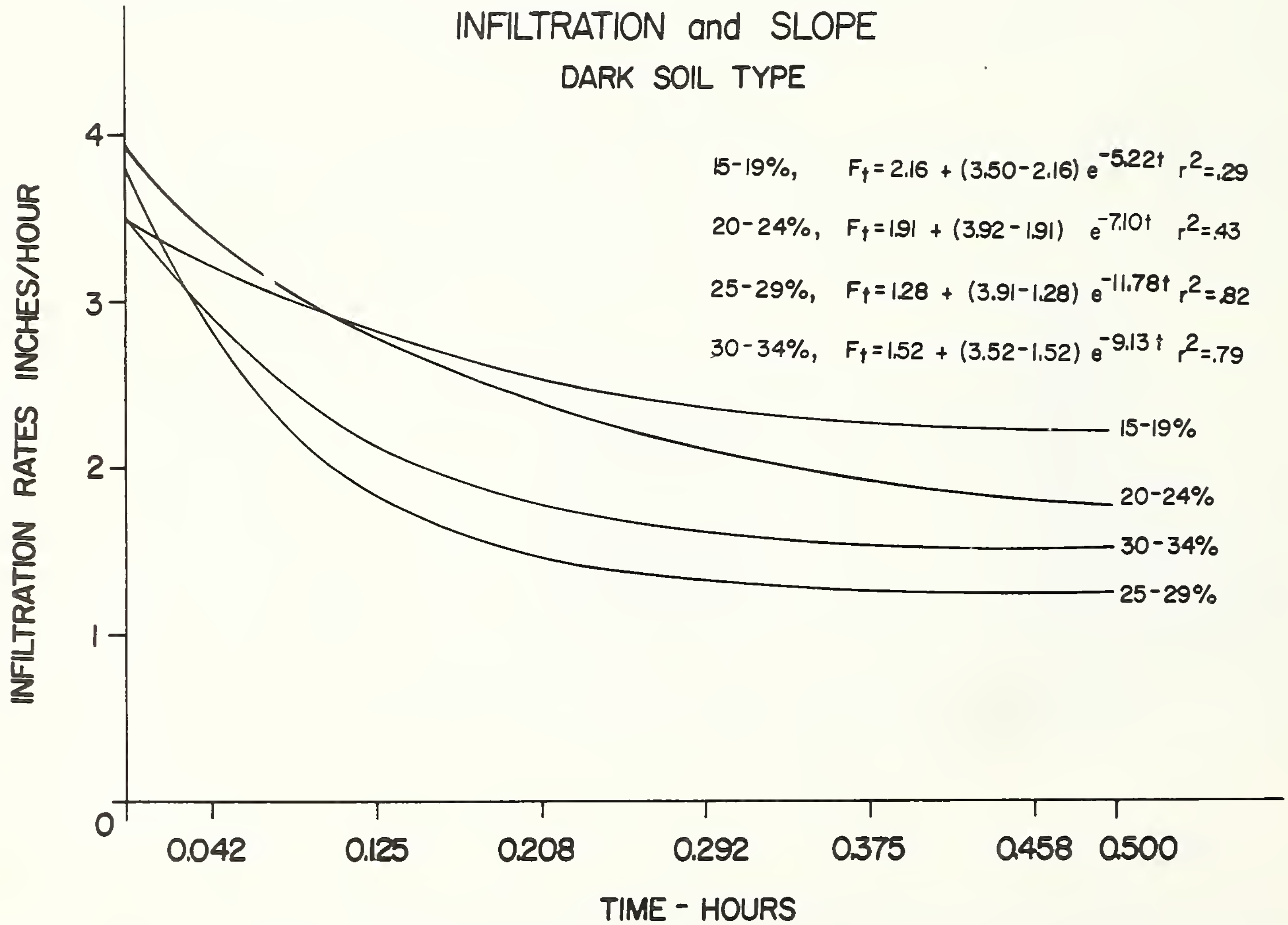


Figure 7.--Horton's average infiltration equations for four slope classes within the dark soil type. Each curve represents four infiltrometer runs of six observations.

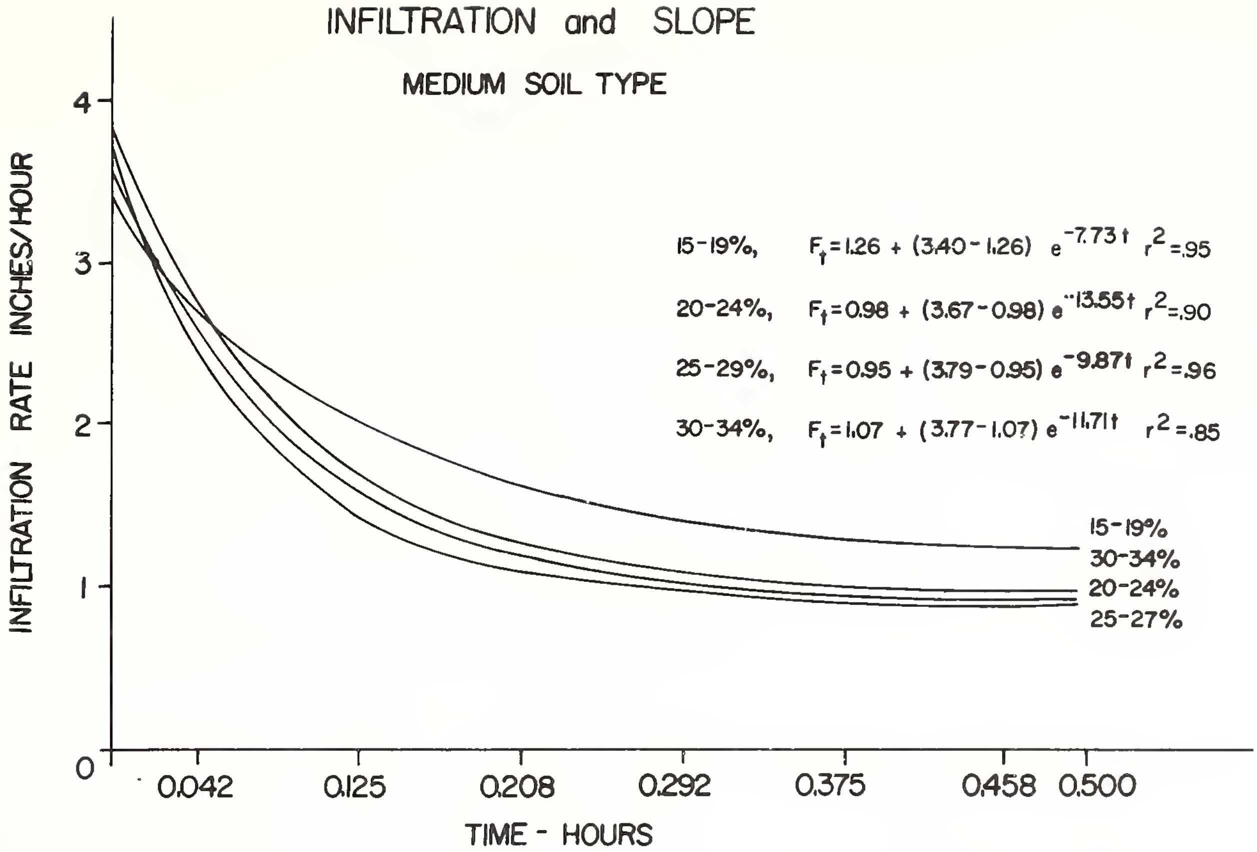


Figure 8.--Horton's average infiltration equations for four slope classes within the medium soil type. Each curve represents four infiltrometer runs of six observations.

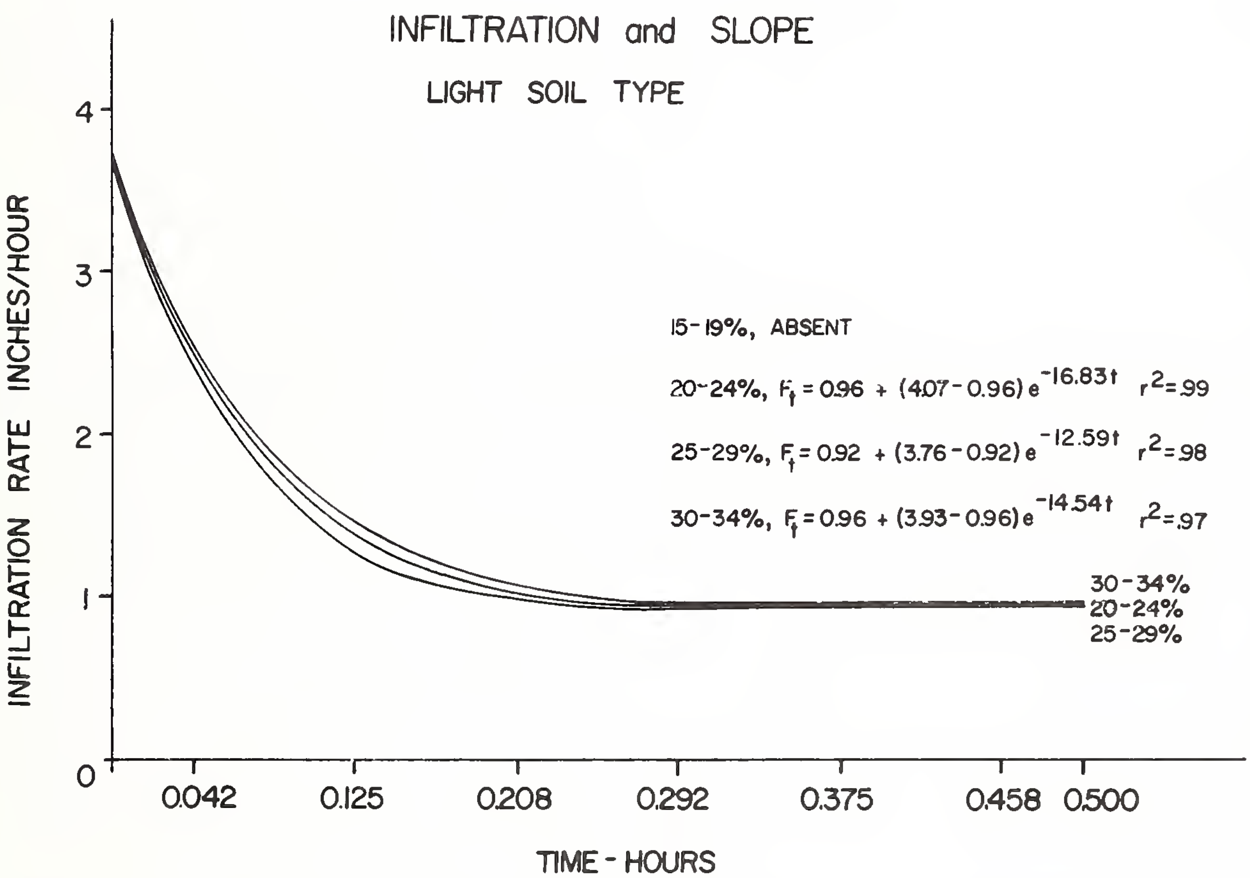


Figure 9.--Horton's average infiltration equations for three slope classes within the light soil type. Each curve represents four infiltrometer runs of six observations.

SOIL EROSION

The dark soil eroded least during the 30-minute run (2.1 tons/acre; 4.71 MT/ha) followed by the medium soil (10.1 tons/acre; 22.6 MT/ha) and then the light soil (23.2 tons/acre; 52.0 MT/ha), (fig. 10).

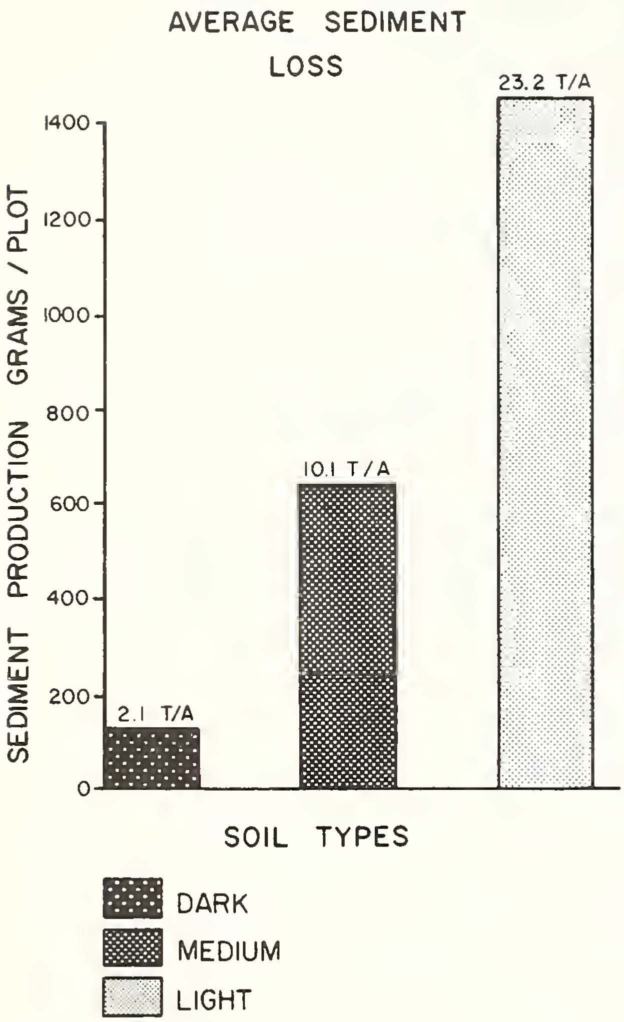


Figure 10.--Average sediment loss for three soil types resulting from 3-inch per hour, 30-minute duration infiltrometer run. A "1-way AOV" and Duncan's multiple range test indicated that significant differences are present between the dark and light soils at $\alpha = 0.05$.

An AOV test and Duncan's multiple range test indicated the erosional losses of the dark soil were significantly different (at 0.05) from the light soil groups, but that the medium soil's sediment production was not significantly different from either.

Sediment production varied between slope classes for the dark and medium soils, although within the range of slopes tested, erosion and slope did not show a reliable relationship. The light soil type illustrated no significant response of soil loss to slope.

A cluster analysis was performed using the infiltration constants and the erosional losses from each plot (fig. 11). This test organizes the data into groups of similar infiltration and erosion rates. The greater the similarity within the calculated groups, the greater the likelihood that real difference among groups exists. The fit of the data to the calculated groups can be assessed by the cophenic correlation value, which varies between zero (no correlation of data points) and one (where all the data points within the clusters are identical). Since the initial stratification of the soils was based solely on color, this test can be interpreted as a measure of how closely soil color is indicative of soils having different infiltration and erosion rates.

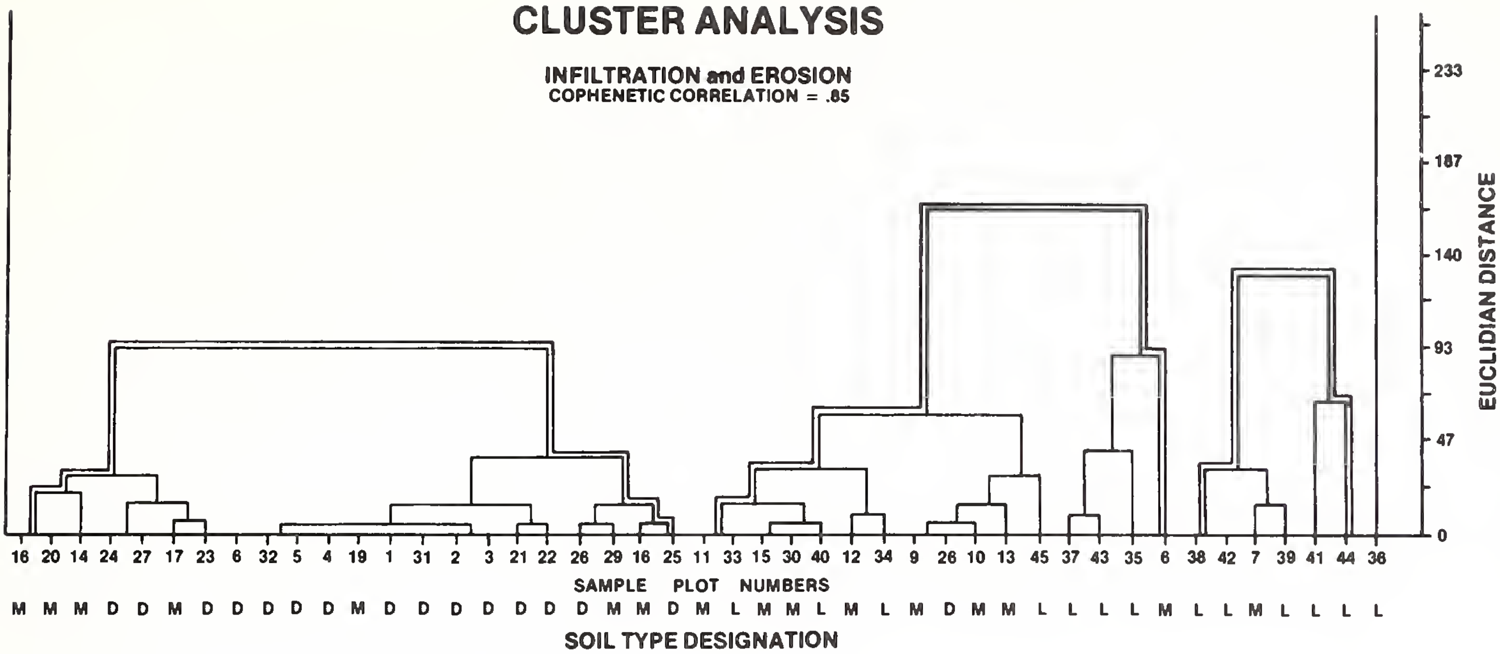


Figure 11.--Euclidian Distance Cluster Analysis of infiltration and erosion rates. The double line depicts the three clusters which broadly correspond to the dark, medium, and light soil types. They were orginally stratified on the basis of color.

The cluster analysis depicted three distinct groups with a cophenetic correlation of 0.85 (a high value, indicating the groups are generally separate and distinctly different). These groups broadly correlated with the orginal three groups based upon soil color. The first cluster was composed of 68 percent dark soil and 32 percent medium soil. The second cluster was made up of 50 percent medium soil, 45 percent light soil, and 5 percent dark soil. The remaining cluster was 86 percent light soil type and 14 percent medium soil type. The observed variability is probably the result of some mixing of soil types during dump construction and the subsequent unintentional sampling of those mixtures.

DISCUSSION

The MOR, antecedent moisture, and textural values of the three soils do display some separate and distinct physical characteristics. Together they tend to separate the dark and light soils into elemental soil units and indicate that the medium soil type is probably a mixture of the dark and light.

As regards infiltration and erosion rates, the medium soil type consistently fell between the dark and the light soils. This, in conjunction with the results of the cluster analysis, which showed the medium soil was made up of a mixture of dark, light, and medium soil types, indicates that the medium soil type is probably a mixture of the dark and light.

The fact that a medium soil group cluster appeared at all in the analysis, indicates this mixture does have enough unique properties to still be considered a separate soil group.

The differences between soil types with respect to erosion were inversely correlated with infiltration. The light soil's low infiltration rates resulted in higher overland flow volumes, which in turn transported greater sediment loads. This partially explains the light soil's ability to produce about 10 times the volume of sediment from the same infiltrometer storm as did the dark soil.

While color was a useful indication of separate soils in this study, under normal field conditions it probably would not be a consistently reliable predictor of soil characteristics. For that reason, a stepwise multiple linear regression was done using the physical characteristics of the soils in order to try to identify another means of labeling hydrologically desirable soil types.

The resulting equation for sediment production is:

$$S = 46.4 \text{ (percent silt)} + 13.8 \text{ (MOR-milli-bars)} - 824, \quad r^2=0.614$$

S = Grams of sediment (infiltrometer-based comparison).

This equation provides an objective methodology for ranking any number of soils in relation to those soils' relative erosivities. Because of the artificial nature of rainfall simulation, this equation cannot be expected to predict soil losses occurring from a natural rainfall event. It is intended to display only the relative magnitudes of differences between the tested soils (under the conditions of an essentially vegetation-free surface).

The inclusion of silt in this instance confirms earlier research which shows increased susceptibility to erosion with increasing silt content (Packer and Christensen 1977; Farmer and Van Haveren 1971; Wishmeier, Johnson, and Cross 1971).

The MOR test is not reflective of just one specific soil property, but rather is a response to many soil characteristics. Specifically what MOR is measuring is unknown, although it has been strongly correlated with high levels of exchangeable sodium and infiltration rates (Farmer and Richardson 1976).

CONCLUSIONS

1. Different sedimentary strata within the phosphate-bearing formations of southeastern Idaho, when used as surfacing material on overburden dumps, exhibit different infiltration and erosion characteristics.

2. The magnitude of these differences is such that separation and stockpiling of specific strata for use as surfacing material is a viable consideration.

3. On the Maybe Canyon mine, dump No. 2, the light colored surface material displayed a 10-fold difference in erosional losses compared to the dark material [23.2 tons/acre (52 MT/ha) as compared with 2.3 tons/acre (5.2 MT/ha)]. Infiltration constants for the dark, medium, and light soil types were:

1.73, 1.08, and 0.95 inches per hour (4.39, 2.74, and 2.41 cm per hour).

4. Future comparisons of geologic strata are possible and fairly easily accomplished through measurments of the strata's silt percent and modulus of rupture. Both of these tests are relatively fast and inexpensive (Black 1965).

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Infiltration and erosion characteristics of three phosphate mine overburden soils were compared using a drip type infiltrometer. A comparative analysis of the soils' physical properties, and their infiltration and erosion rates, revealed distinct differences between soil types. The study concluded that successive layers of sedimentary rock overburden (the top soils tested) can exhibit significantly different hydrologic properties when used as surface fill.

KEYWORDS: phosphates, infiltration, erosion, overburden dumps, soil properties

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The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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